Development of High-Resolution Muon Tracking Systems Based on Micropattern Detectors

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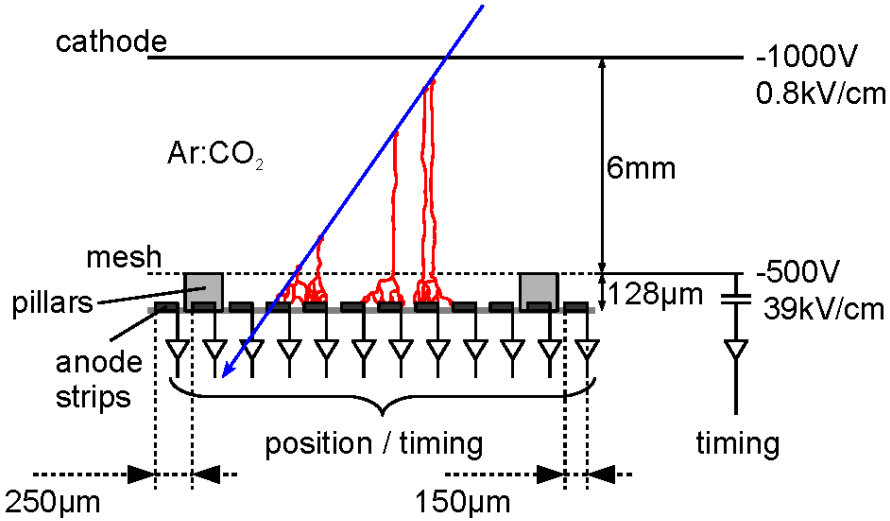
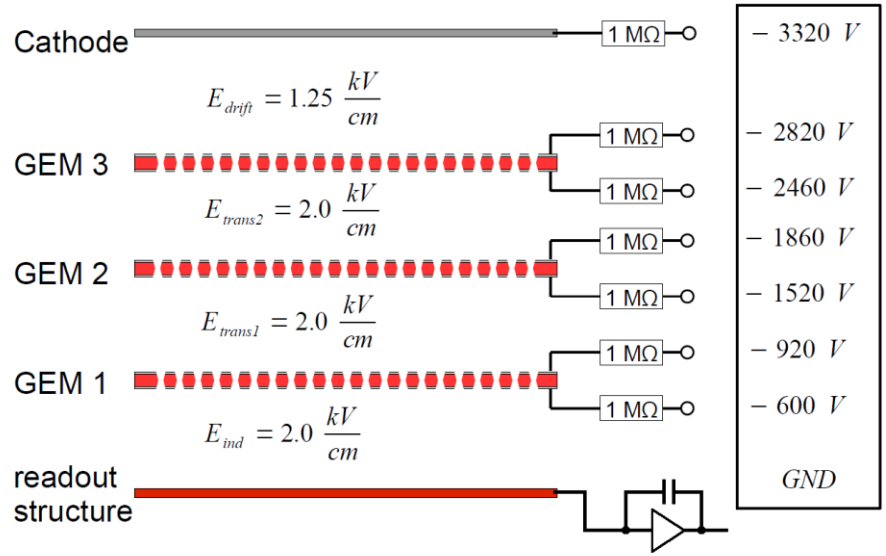
Introduction and Motivation

- tracking system for 140 GeV muons @ H8-beamline/CERN
- large area detector systems with good spatial resolution $\Delta x \approx 60\mu m$ and high rate capability ($O(m^2)$)
- investigate general behavior of GEM and Micromegas
- investigate spatial resolution of GEM/Micromegas under irradiation with γ @ GIF/CERN and n @ MLL tandem accelerator Munich

Functional Principle Micromegas/GEM

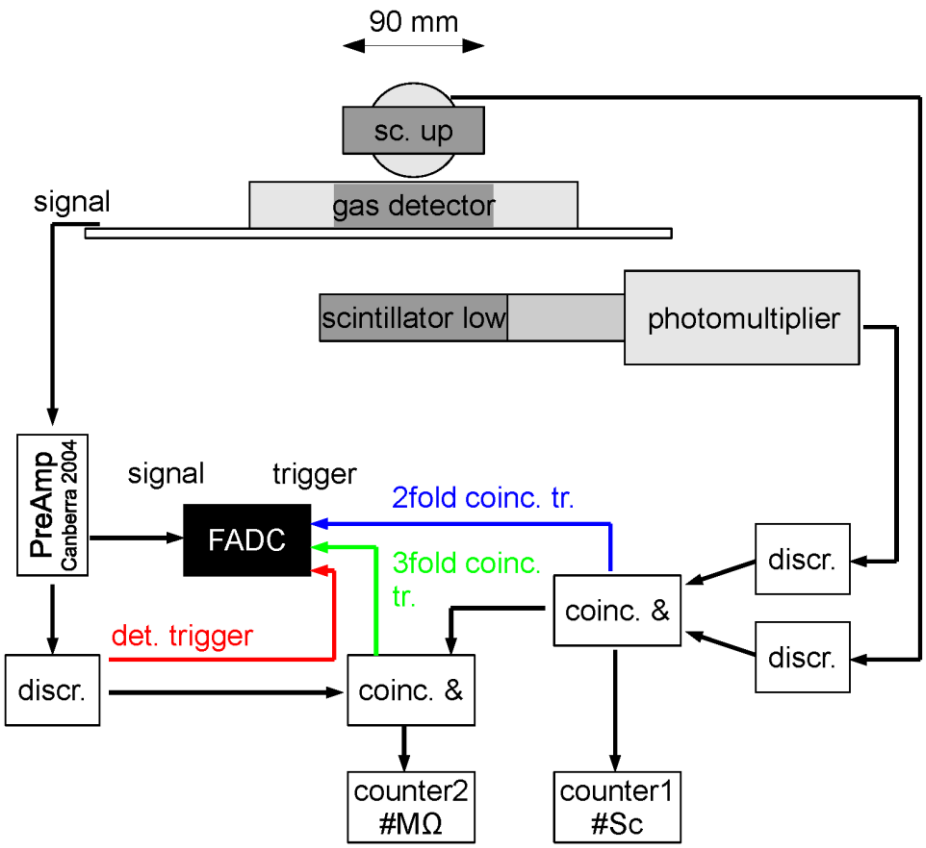


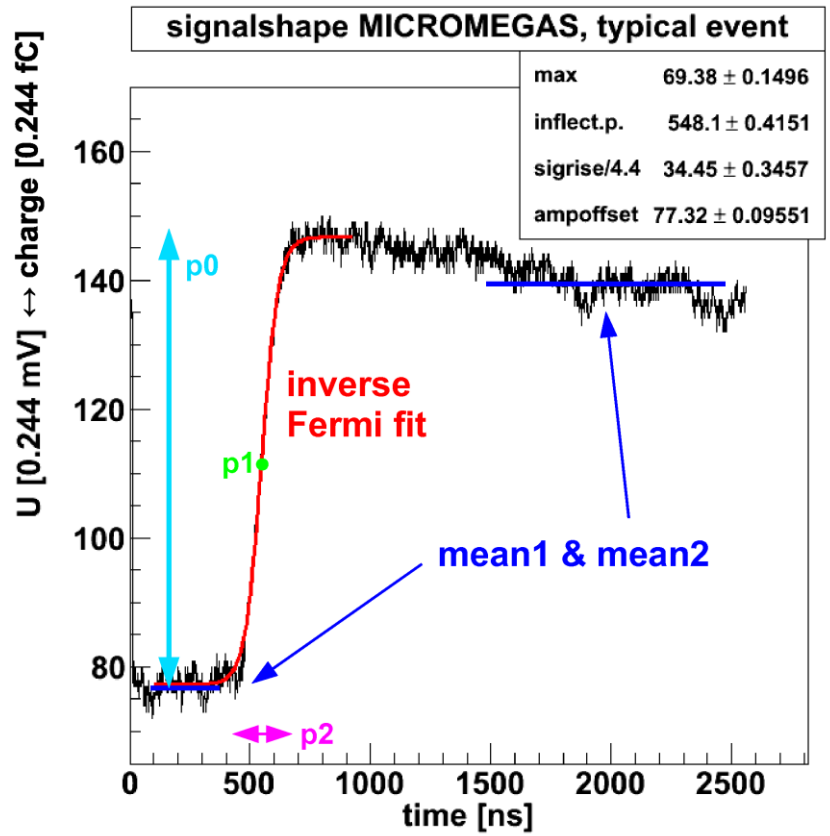


- MICROMEsh GAS detector
- 360 strips with 150µm width and 250µm pitch → active area: 90mm x 100mm
- 128µm amplification gap
- 5-7mm drift gap
- $Ar:CO_2$ at NTP

- triple GEM detector
- active area: 100 mm x 100 mm
- unsegmented anode or strips with 150µm width and 250µm pitch
- GEM spacing: 2-3mm
- drift gap: 3-4mm

flashADC: Setup & Data Analysis

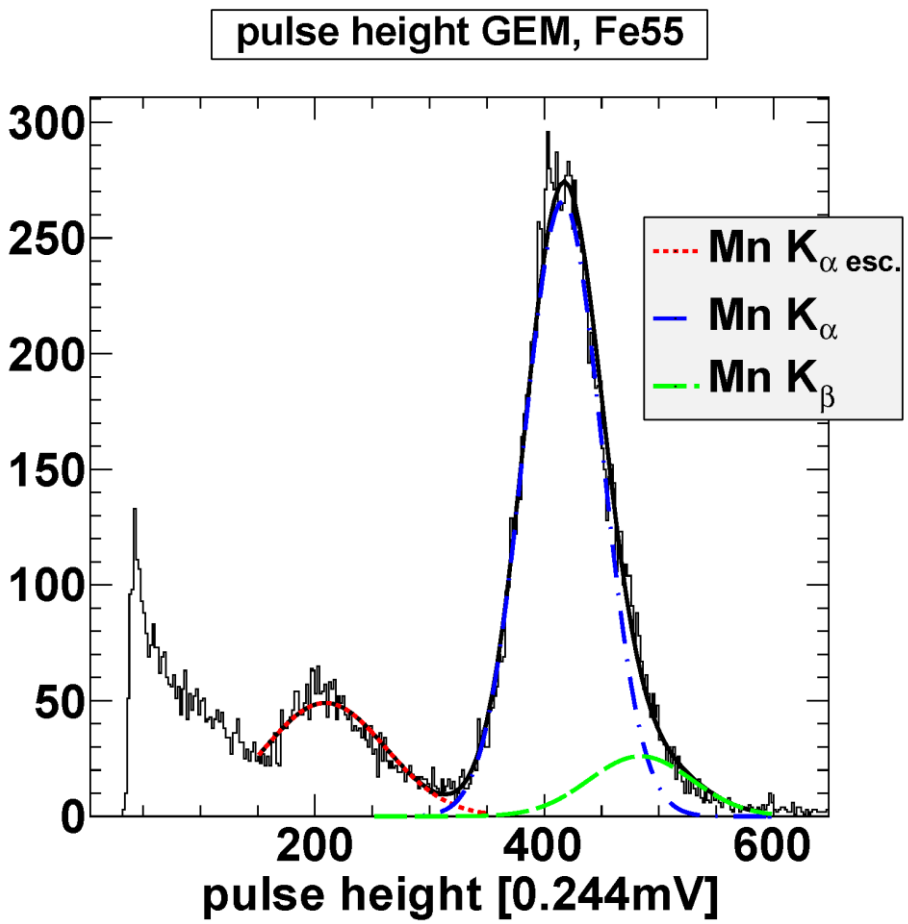


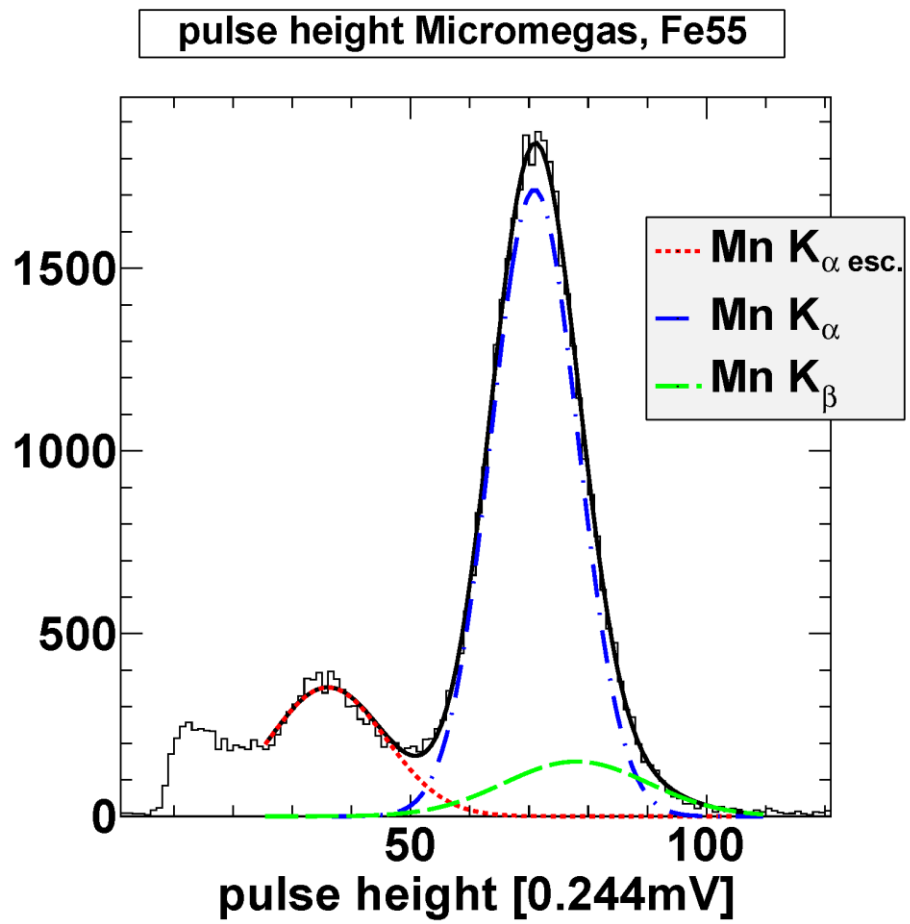


- 12 bit 1GHz fADC with 2520ns recording time
- trigger: **coincident** or **single**

- pulse height, rise time, timing
- cut: mean2-mean1>3σ

Energy Resolution @ 5.9keV X-rays



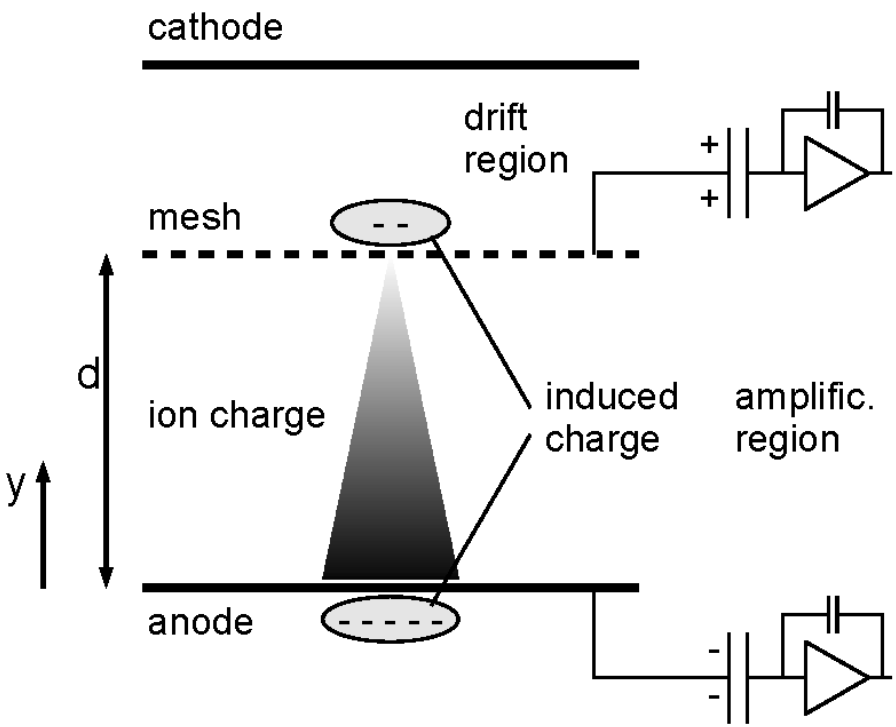


GEM: $dE/E_{FWHM} = 18\%$

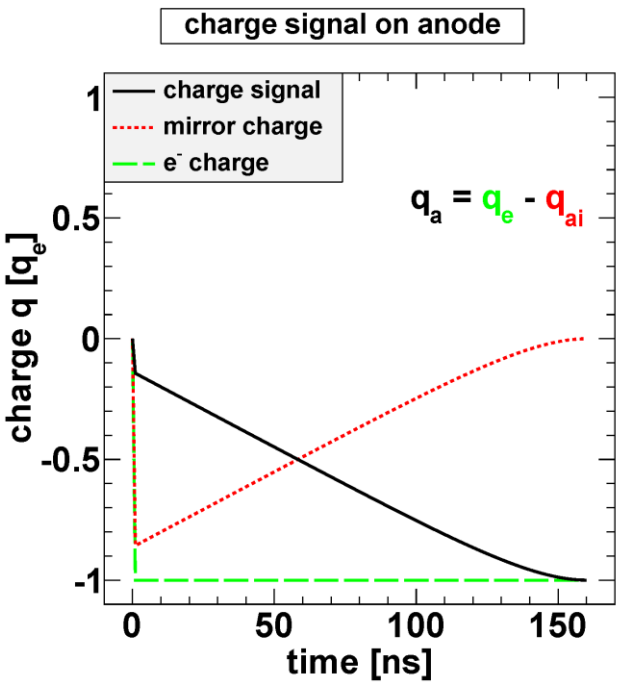
Micromegas: $dE/E_{FWHM} = 24\%$

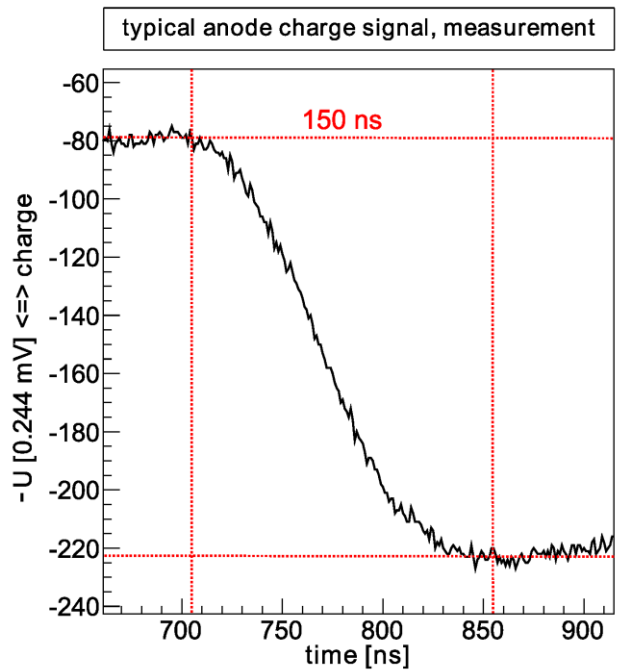
Micromegas: Signal Formation

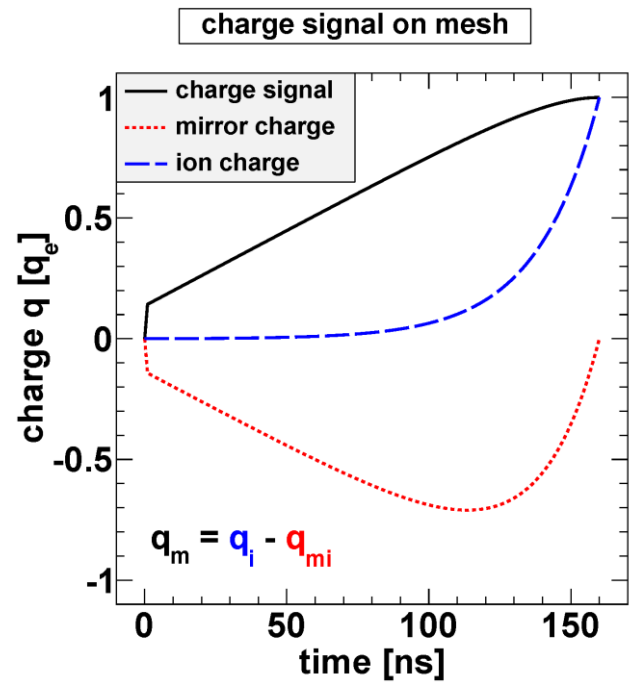
- e^- from ionization reach amplification gap: **10-100ns**
- gas amplification: **<1ns**
- total e^--charge on anode, ion cloud induces negative surface charge on anode and mesh
- ions from gas amplification drift towards mesh: **150ns**
- observable charge on
  - anode: $q_a(t) = q_e(t) - q_{ai}(t)$
  - mesh: $q_m(t) = q_i(t) - q_{mi}(t)$



Micromegas: Signals Calculated & Measured

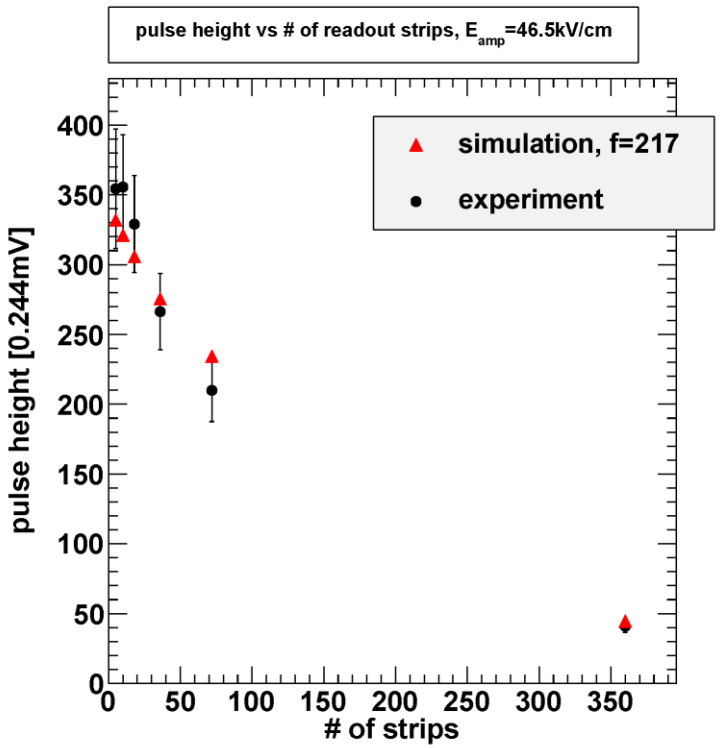


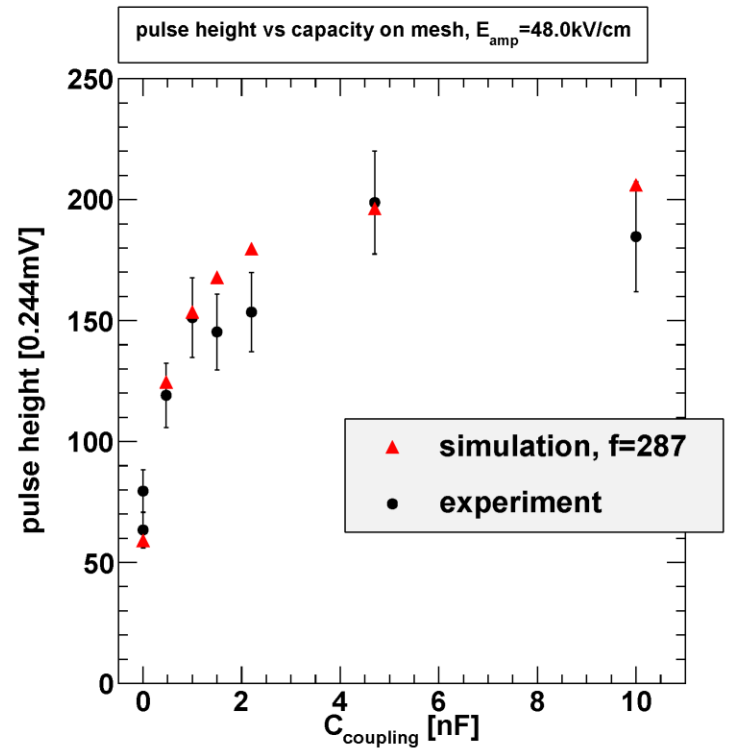




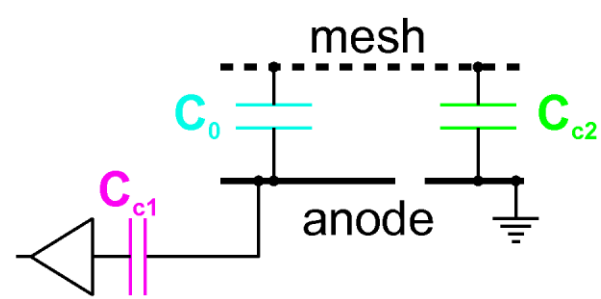
- overall behavior reproduced by calculation
- charge sensitive preamp not fast enough to resolve steep initial rise (14% of total charge within 1ns → timing)

Micromegas: Capacitance & Pulse Height



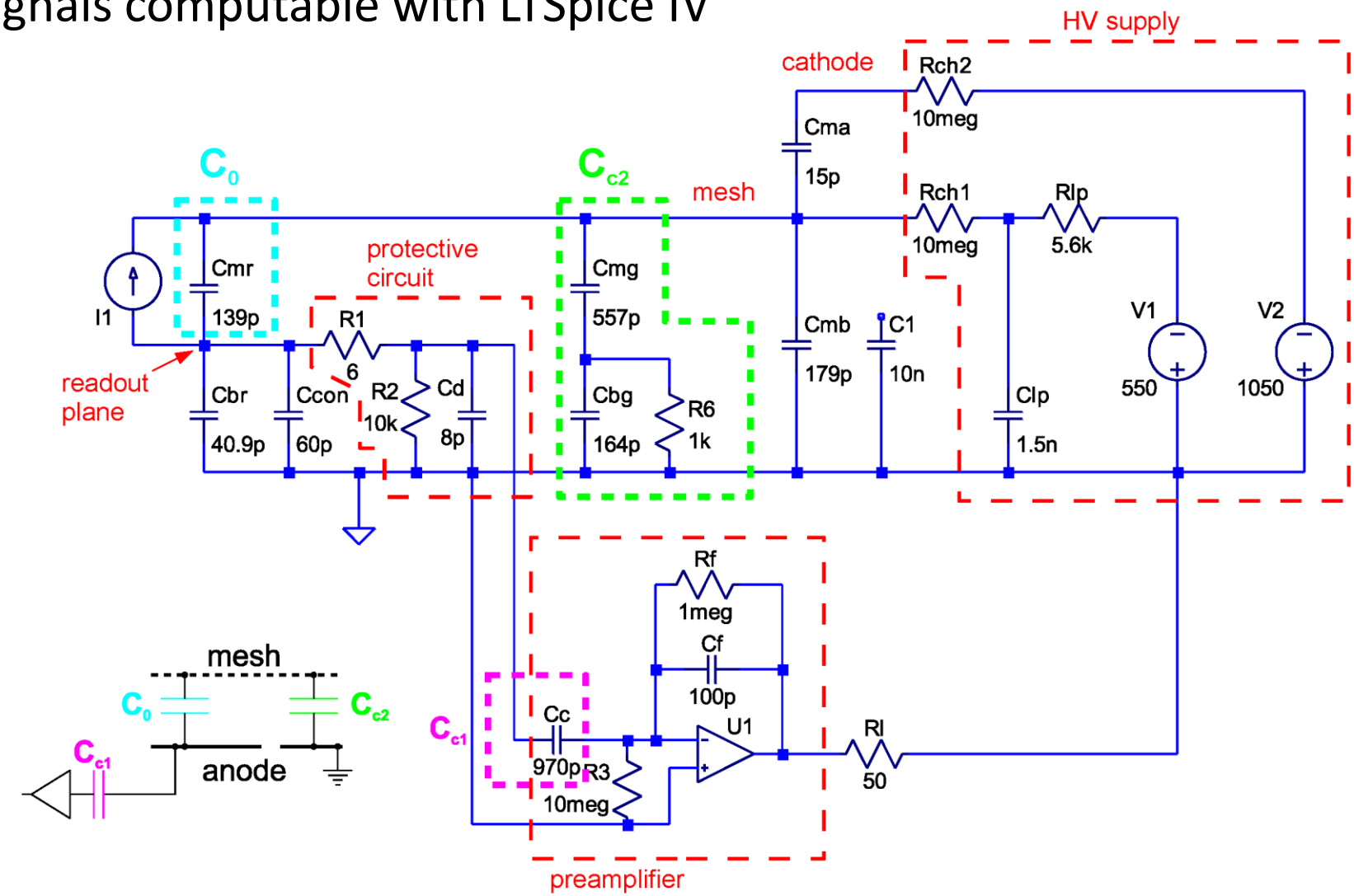


- strong influence of the capacitances in the detector-preamp network onto pulse height
- agreement between **data** and **calculation**



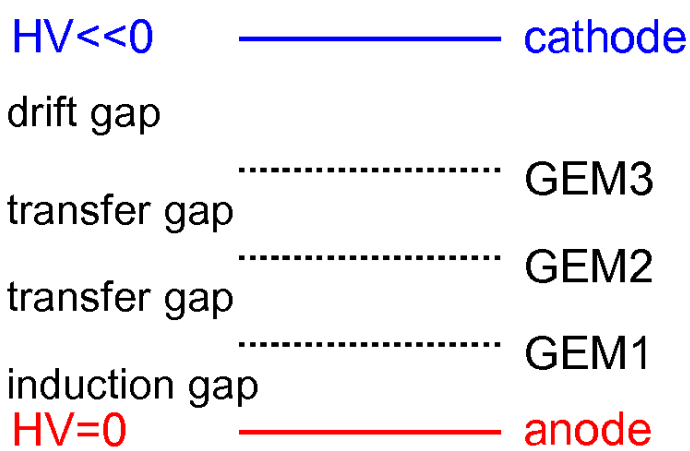
Micromegas: Capacitance & Pulse Height

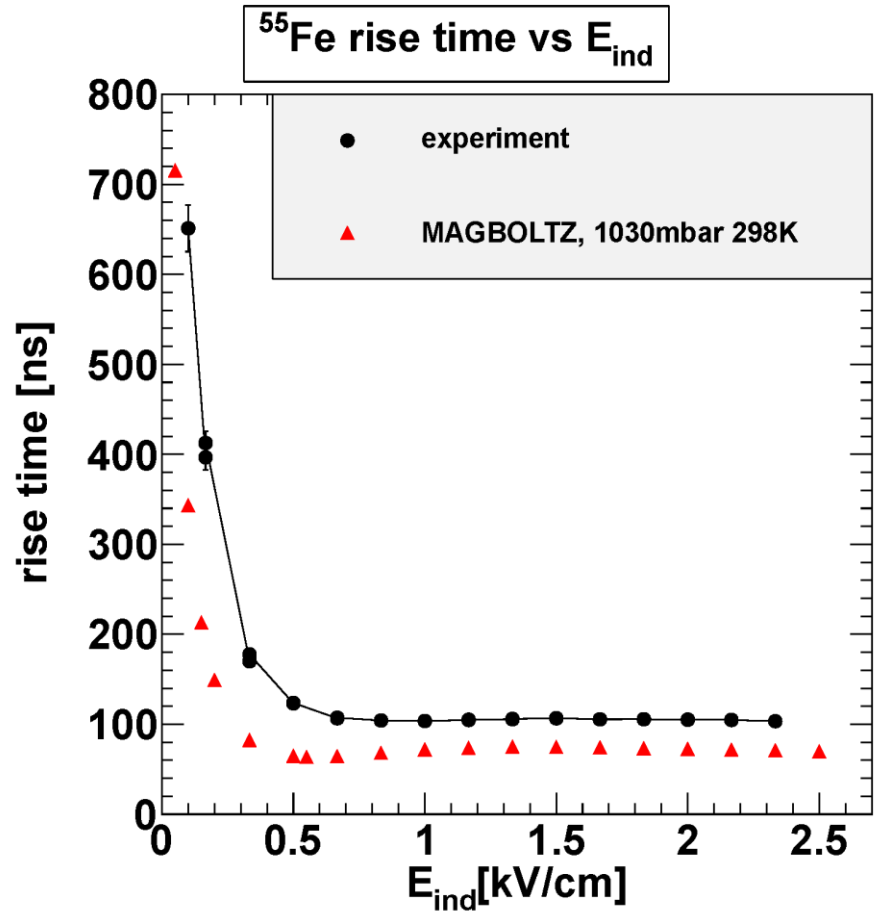
- signals computable with LTSpice IV



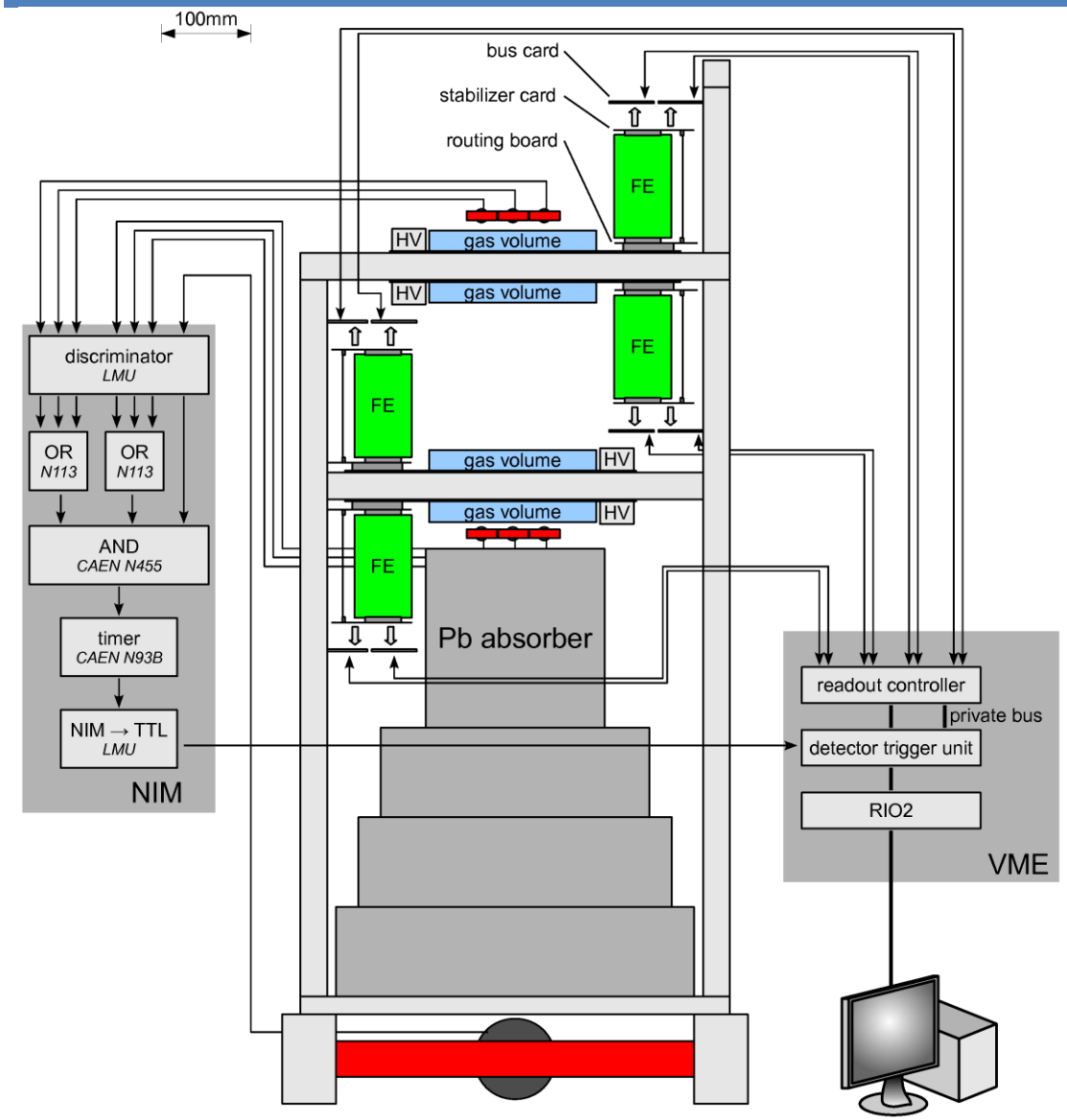
GEM: Signal Formation

- signals caused by e^--drift in induction gap: $v_{drift} \approx$ const. → $t_{rise} \propto v_{drift}$
- increase of pulse height with decreasing number of read out strips (not as strongly as in Micromegas)



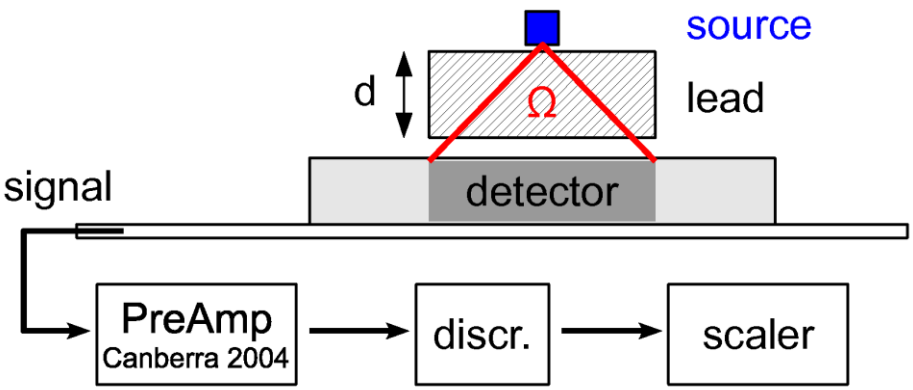


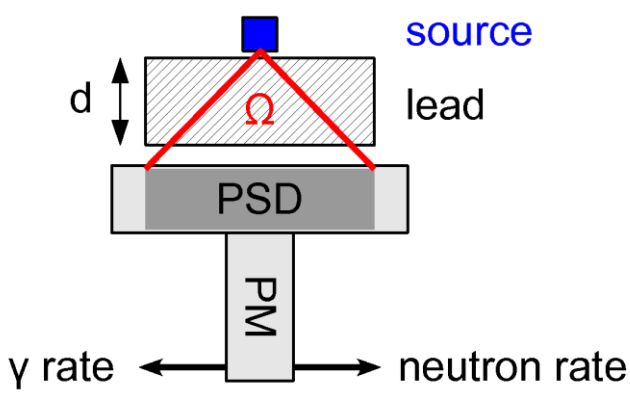
Muon Tracking System: Setup



- 4 Micromegas
- 2-dimensional track reconstruction
- readout: 6 Gassiplex FEs per detector, with 64 channels each, 1500 channels in total
- trigger: 6 scintillators (3rd track coordinate) + 1 scintillator (E_μ>600MeV)
- irradiation with ^{137}Cs (γ) and ^{252}Cf (γ + n)

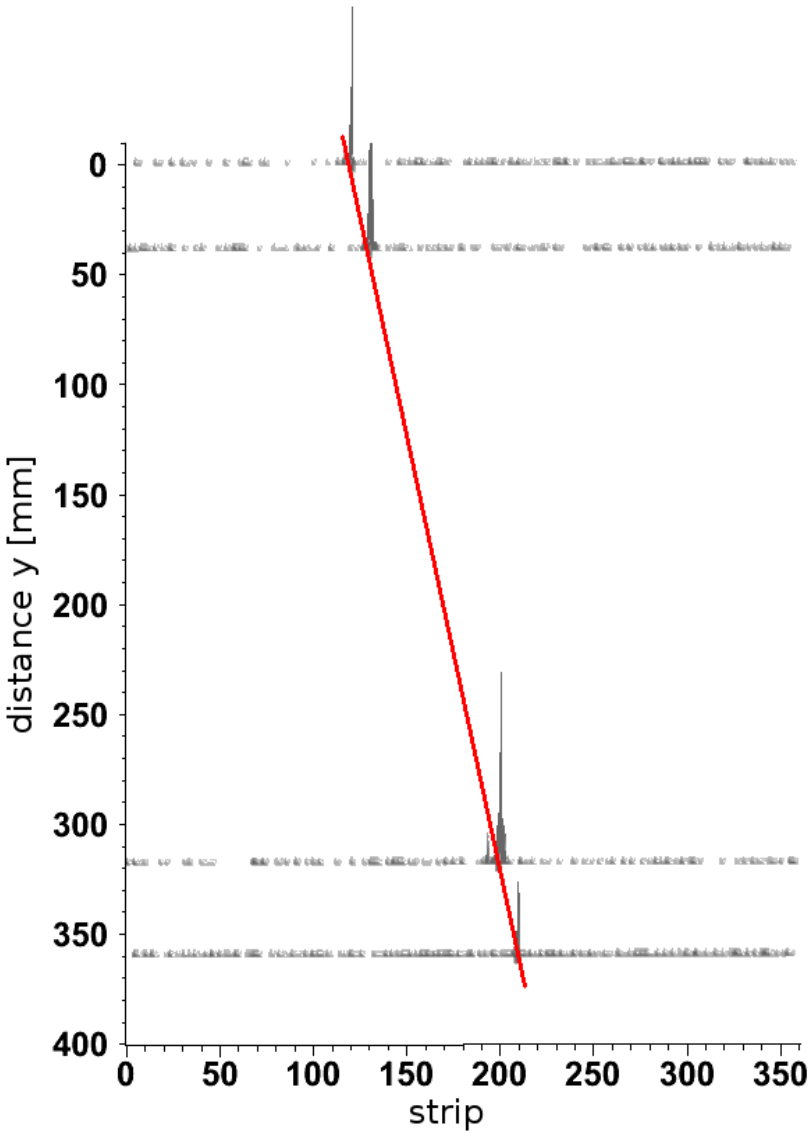
Micromegas: Efficiency to n and γ & reachable flux





- activity of source and solid angle known → expected rate
- efficiency = $rate_{meas}/rate_{expec}$
- adding 10-50mm lead → discrimination between γ and n
- **^{137}Cs**:
  - E_γ = 662keV,
  - flux $rate_\gamma$ = (1.59±0.04)MHz,
  - **→ ε_γ = (2.6±0.2) x 10^{-3}**
  - f_{spark} = (0.24±0.01)min^{-1}
- **^{252}Cf**:
  - E_n up to 8MeV, E_γ ≈ keV … 4MeV,
  - flux $rate_n$ = (9.1±0.3)kHz,
  - flux $rate_{\gamma,\ fission}$ = (16.4±1.3)kHz,
  - **→ ε_n < 6.8 x 10^{-4} @95% CL**,
  - → ε_γ = (1.5±0.4) x 10^{-3}
  - f_{spark} = (0.50±0.04)min^{-1}

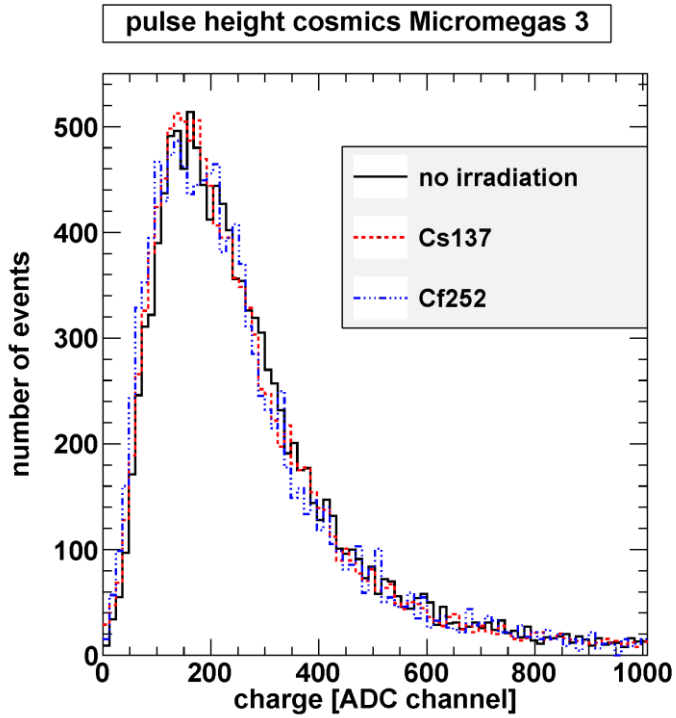
Muon Tracking System: Data Analysis



- hits: center-of-gravity method, regarding only those strips with amplitude > 3σ around the one with maximum amplitude
- track reconstruction: linear fit through all detectors → alignment
- spatial resolution: compare prediction by 2 detectors with measured hit in 3rd detector:
  $\delta = r_3 - r_2 \cdot d_{13}/d_{12} - r_1 \cdot (1 - d_{13}/d_{12})$
  $\rightarrow \Delta\delta = \Delta\delta(\Delta r_1, \Delta r_2, \Delta r_3)$
- 4 different triplets of 4 detectors & 4 Δr_i → solveable

Micromegas: Δr under Irradiation

Micromegas	Δδ, no irrad.	Δδ, ^{137}Cs
1	105±5 µm	108±5 µm
2	108±5 µm	108±6 µm
3	118±7 µm	117±5 µm
4	122±7 µm	119±5 µm



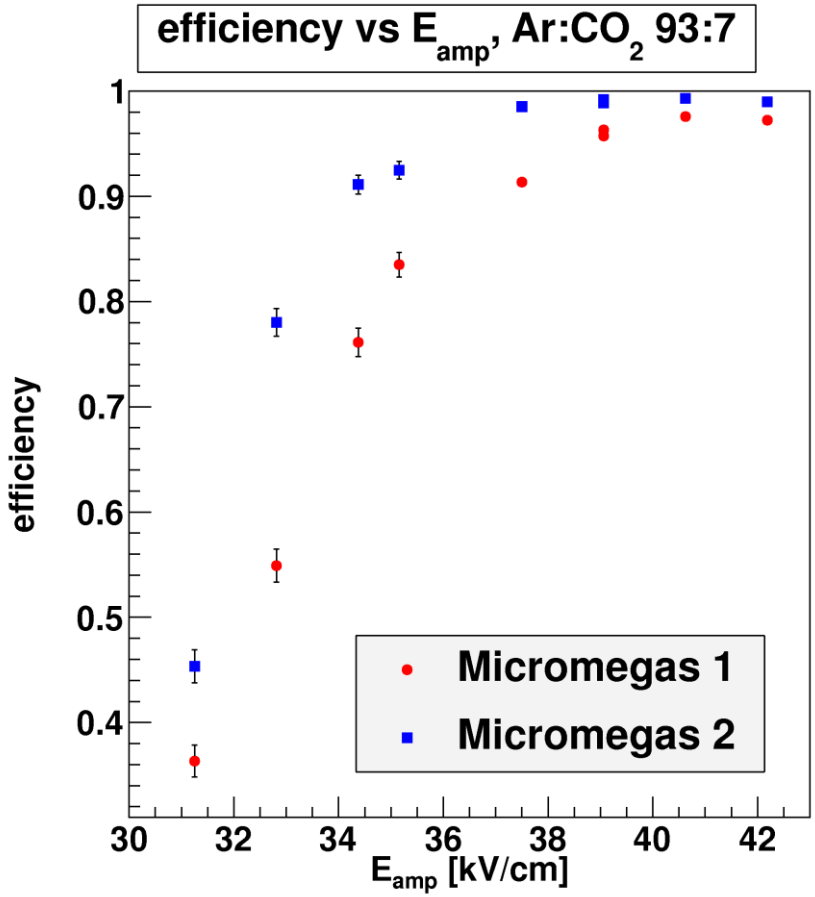
- no irradiation:
  - $(\Delta r_i)^2 = (\Delta r_{int})^2 + (\Delta r_{ms})^2$
  - $\Delta r_{ms} = 0.13\ \mu m/mm \cdot d_{ui}$
  - $\Delta r_{int} \approx 80 \mu m$
- γ-irradiation: no significant increase
- n-irradiation: no significant increase expected (since pulse height remains unchanged)

Summary

- Micromegas and GEM detectors have been investigated,
  a muon tracking system has been set up
- efficiencies to muons of up to 99% are achieved, the FWHM energy resolution for 5.9keV X-rays is 18% (GEM) and 24% (Micromegas)
- models for signal formation have been presented, quantitative description of data by Micromegas
- single detector spatial resolution of Micromegas around 80µm,
  no degradation under γ-irradiation,
  no degradation under n-irradiation expected

Thank you!

backup: Efficiency for Muons



- efficiency for muons up to 99% in both detector types
- stable operation O(week)
- difference in efficiency ↔ difference in pulse height